C. Critical Variables in the Design of Mentholated Cigarettes

1. Background

Numerous studies (1-9) of the effects of construction parameters on non-menthol cigarette performance have been conducted. In each of the studies, the effects of cigarette physical characteristics on delivery performance were determined and quantitative models were developed. These models have been used for some time to aid in the design of in-market products and prototypes for research.

Over the past few years, several studies (10-22) and reviews (23,24) have been completed that investigated the influence of cigarette configuration variables on the delivery and the migration of menthol. Each of these studies was designed to investigate specific problems associated with mentholated products. Therefore; these studies are of limited usefulness in the prediction of menthol deliveries and in understanding the process of menthol migration within the cigarette over a wide range of product configurations.

To develop the capability to predict smoke menthol deliveries and to understand the extent and ramifications of menthol migration, a systematic study of the effects of cigarette configuration variables is required. The end result of such a study would be a model that allows estimation of the menthol delivery of a product, given the pertinent configuration variables.

2. Variables Which Affect Menthol Delivery and Migration

o Menthol Parameter Screening Study

Recently, a screening study (25) was completed to address this issue (RDM, 1983, No. 11, "Screening Study of Variables Which Affect Menthol Delivery and Migration," A.B. Norman and T.A. Perfetti, March 14, 1983.). This study was the first to rank variables in terms of their importance in affecting menthol delivery and migration. Six variables (tow item, tipping porosity, tobacco rod length, tobacco menthol load, plasticizer level, and cigarette age) were screened in a Plackett-Burman designed study (29). The design and variable levels are shown in Tables I & II. A total of 22 responses were measured, including tobacco chemistry analyses (six), cigarette physical analyses (four), and smoke chemistry analyses (ten). Statistical analyses of the results yielded the following ranking of the variables important to migration of menthol:

Tobacco Menthol> Tobacco Rod Length> Plasticizer Level

The variables which affect smoke menthol delivery were ranked as follows:

Tow Item > Tobacco Menthol > Tipping Porosity > Tobacco Rod Length > Plasticizer Level.

o Results and Discussion

The effects of the variables on the responses are shown in Tables III-VII. Only statistically significant effects ($p<-0.05$) were included in the tables. The effects of the variables on tobacco analyses are shown in Table III, the effects on smoke menthol responses are shown in Table IV, and the effects on menthol distribution within the cigarette are shown in Table V. The effects of the variables on smoke chemistry and physical measures are summarized in Tables VI and VII, respectively.

No effects of the variables on the tobacco analyses were expected, with the exception of a decline in moisture over the aging period (1 to 6 weeks). The moisture decreased by 0.5% over the aging time (Table III). Small but statistically significant effects of tobacco menthol level on total sugars and moisture were observed. A small effect of time on total sugars was also observed.

Menthol delivery (Table IV) was affected by tow item, tipping porosity (i.e., air dilution), menthol level, and tobacco rod length. Each of these effects was in the expected direction, e.g., increased air dilution or tow item surface area decreased the menthol delivery while increased menthol load or rod length increased delivery. Although the magnitudes of the effects were different, the directions of the effects paralleled those found for FTC 'tar' (Table VI). The changes in 'tar' delivery caused by the tow item and tipping porosity changes were approximately equal in magnitude (Table VI). However, the tow item effect on menthol delivery was about twice as large as the effect of tipping porosity (Table IV). To better understand this observation, the menthol/'tar' delivery ratios were statistically significant while effects from tow item and rod length were not significant. This observation (Table IV) indicates that air dilution level has an effect on menthol delivery which is different from its effect on 'tar'. However, tow item and tobacco rod length changes have proportionately similar effects on 'tar' and menthol deliveries. Interestingly, plasticizer level was found to have a statistically significant effect on menthol/'tar' ratio. The effect of plasticizer level on menthol delivery was small and almost below the significance level cut-off point (Appendix 6). However, the plasticizer level was found to significantly affect some of the other menthol responses (e.g.; filter menthol; Table V, menthol/'tar' ratio; Table IV, menthol filter efficiency; Table IV). It therefore seems likely that the amount of plasticizer interacts with migration and delivery of menthol (23,28).

The menthol retained on the filter after smoking (Table IV) was significantly affected by the tow item, menthol level, and aging time. As tow item surface area is increased, retention of smoke particulates increases. Thus, increased retention of menthol as a function of tow item surface area is expected. No significant effect of dilution on the retention of menthol was observed, however. An increase in retention was expected due to increased filtration efficiency with increased air dilution. In fact, menthol filtration efficiency did increase with increased tipping porosity (Table IV). A significant increase in menthol retention was observed due to aging time. This may be due to migration of menthol from the tobacco rod to the filter over the aging period (16). However, menthol was measured on the filters before smoking. No significant effect of aging time was observed for this response (Table V). Previously, aging time was shown to be important to menthol migration and delivery (10,11,16,20,23,30), so this observation was unexpected. The plasticizer level and tobacco rod length, in addition to the tow item and tipping porosity, had significant effects on the menthol filtration efficiency. The tow item and tipping porosity effects were as expected based on the smoke particulate efficiency analogy. Increased plasticizer and aging time increased menthol filtration efficiency while increased tobacco rod length decreased menthol filtration efficiency.

The effects of the variables on migration of menthol from the tobacco rod to the filter were determined by measuring menthol levels on the filter, tobacco rod, and the total cigarette. Effects of the variables on these measures are summarized in Table V. As expected, the tobacco menthol level significantly affected the amounts of menthol found in the cigarettes, filters, and tobacco rods. Similarly, increased tobacco rod length increased the amount of menthol in the cigarette, filter, and tobacco rod.

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Increased plasticizer levels caused an increase in the amount found on the filter, however, a simultaneous decline in menthol on the tobacco rod was not observed. This observation must be an artifact since menthol level in the total cigarette did not change with plasticizer level. Aging produced a decline in tobacco rod menthol but did not significantly affect the filter menthol level. Since no significant change in total cigarette menthol over time was noted, an increase in filter menthol had been expected.

The effects of the variables on standard smoke analyses (FTC 'tar', nicotine, CO, etc.) are shown in Table VI. As expected, increased tow item surface area decreased the particulate phase smoke deliveries, however, no significant effect on carbon monoxide delivery was observed. The tipping porosity (air dilution) increase caused significant decreases in particulate and carbon monoxide deliveries. The tobacco rod length increase caused increases in smoke deliveries. Aging had a significant effect on the puff count although this observation may be due to the decline in tobacco moisture over the aging period.

The effects of the variables on several physical cigarette measures are shown in Table VII. As expected, cigarette pressure drop with vents open (DHO) increased with increased tow item surface area and decreased with increased tipping porosity. However, it was not significantly affected by tobacco rod length . Pressure drop with vents closed (DHC) increased with increasing tow item surface area and tobacco rod length. A small but significant effect of menthol level was also observed for the vents-closed pressure drop but this effect is probably an artifact arising from the order of making the test cigarettes. All cigarettes with the same menthol load were made at the same time, but the two menthol levels were prepared at different times. Apparently, the tobacco rod pressure drops were consistently higher for the high menthol products. Air dilution increased with increases in tow item surface area and tipping porosity. The effect of tow item surface area on air dilution is caused by the increase in pressure drop upstream of the perforations which resulted from the tow item change. As expected, filter efficiency (for total particulates) increased with increasing tow surface area and tipping porosity.

o <u>Conclusions of Menthol Parameter Screening Study</u>

Cigarette construction variables produce effects on menthol delivery which parallel (in direction) their effects on 'tar' delivery. Filter tow and tobacco rod length changes have proportionately similar effects on menthol and 'tar' deliveries. Air dilution, however, appears to have a larger effect on menthol than 'tar'. Strong, consistent effects of plasticizer level were not observed but it appears that this variable may interact with menthol delivery and migration of menthol into the filter.

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TABLE I. THE PLACKETT-BURMAN SCREENING DESIGN

Trial	Tobacco Menthol	Tobacco Rod Length	Tipping Porosity	Tow Surface Area	Filter Plasticizer Level	Aging Time
1	+	+	-	+	+	+
2	+	-	+	+	+	-
3	-	+	+	+	-	-
4	+	+	+	-	-	-
5	+	+	-	-	-	+
6	+	-	-	-	+	-
7	-	-	-	+	-	+
8	-	-	+	-	+	+
9	-	+	-	+	+	-
10	+	-	+	+	-	+
11	-	+	+	-	+	+
12	-	-	-	-	-	-

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TABLE II. VARIABLE LEVELS

Variable	Design Levels +	Design Levels −
Tobacco Menthol (%)	0.8	0.3
Tobacco Rod Length (mm)	74	59
Tipping Porosity (CORESTA)	2800	0
Tow Surface Area (cm^2/cm)	183	75
Filter Plasticizer (%)	14	3
Aging Time (weeks)	6	1

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TABLE III. EFFECTS OF VARIABLES ON TOBACCO ANALYSES

Variables

Response	Tobacco Menthol (%)	Tobacco Rod Length (mm)	Tipping Porosity (CORESTA)	Tow Surface Area (cm^2/cm)	Filter Plasticizer Level (% E-18)	Aging Time (weeks)
% Tobacco Nicotine	----	----	----	----	----	----
% Tobacco Sugars	-0.56	----	----	----	----	-0.46
% Tobacco Moisture	+0.28	-0.34	----	----	----	-0.51

A ---- indicates a nonsignificant response at $p<=0.05$.

A numerical value indicates the estimate of the effect of the response for a change in the variable from its lowest level to its highest level. See Table II for the ranges of each Variable.

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TABLE IV. EFFECTS OF VARIABLES ON SMOKE MENTHOL RESPONSES

Variables

Response	Tobacco Menthol (%)	Tobacco Rod Length (mm)	Tipping Porosity (CORESTA)	Tow Surface Area (cm^2/cm)	Filter Plasticizer Level (% E-18)	Aging Time (weeks)
Menthol Delivery (mg/cigt.)	+0.46	+0.29	-0.22	-0.47	----	----
Menthol Filter Retention (mg/filter)	+0.71	----	----	+0.46	----	+0.47
Menthol Filter Efficiency (%)	----	-5.30	+9.24	+25.84	+5.24	+7.66
Menthol/Tar Ratio	+0.04	----	+0.02	----	-0.01	----

A ---- indicates a nonsignificant response at $p<=0.05$.

A numerical value indicates the estimate of the effect of the response for a change in the variable from its lowest level to its highest level. See Table II for the ranges of each variable.

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TABLE V. EFFECTS OF VARIABLES ON MENTHOL DISTRIBUTION

	Variables					
Response	Tobacco Menthol (%)	Tobacco Rod Length (mm	Tipping Porosity (CORESTA)	Tow Surface Area (cm^2/cm)	Filter Plasticizer Level (% E-18)	Aging Time (weeks)
Cigarette Menthol (mg/cigt.)	+2.84	+1.33	----	----	----	----
Rod Menthol (mg/rod)	+2.62	+0.85	----	----	----	-0.60
Filter Menthol (mg/filter)	+0.53	+0.21	----	----	+0.30	----

A ---- indicates a nonsignificant response at $p<=0.05$.

A numerical value indicates the estimate of the effect of the response for a change in the variable from its lowest level to its highest level. See Table II for the ranges of each variable.

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TABLE VI. EFFECTS OF VARIABLES ON SMOKE CHEMISTRY

	Variables					
Response	Tobacco Menthol (%)	Tobacco Rod Length (mm)	Tipping Porosity (CORESTA)	Tow Surface Area (cm^2/cm)	Filter Plasticizer Level (% E-18)	Aging Time (weeks)
FTC "tar" (mg/cigt.)	----	+2.70	-6.90	-8.40	----	----
Smoke Nicotine (mg/cigt.)	----	+0.26	-0.33	-0.60	----	----
TPM H20 (mg/cigt.)	----	----	-1.75	-1.45	----	----
TPM Delivery (mg/cigt.)	----	+2.90	-8.90	-10.40	----	----
CO Delivery (mg/cigt.)	----	+4.00	-10.20	----	----	----
Puff Count	----	+2.40	+1.30	+0.20	----	-0.50

A ---- indicates a nonsignificant response at $p <= 0.05$.

A numerical value indicates the estimate of the effect of the response for a change in the variable from its lowest level to its highest level. See Table II for the ranges of each variable.

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TABLE VII. EFFECTS OF VARIABLES ON PHYSICAL MEASURES

Variables

Response	Tobacco Menthol (%)	Tobacco Rod Length (mm)	Tipping Porosity (CORESTA)	Tow Surface Area (cm^2/cm)	Filter Plasticizer Level (% E-18)	Aging Time (weeks)
Draft Holes Open (DHO) (mm H20)	----	----	+94.0	+33.7	----	----
Draft Holes Closed (DHC) (mm H20)	-6.60	+11.40	----	+109.0	----	----
Dilution by ITR meter (%)	----	----	+47.70	+6.70	----	----
TPM Filter Efficiency	----	----	+3.50	+34.20	----	----

A ---- indicates a nonsignificant response at $p<=0.05$.

A numerical value indicates the estimate of the effect of the response for a change in the variable from its lowest level to its highest level. See Table II for the ranges of each variable.

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3. Effects of Cigarette Construction Parameters and Menthol Load on Menthol Cigarette Performance

o Menthol Parameter Study

The four variables identified in the Menthol Parameter Screening Study (25) as most important in affecting menthol delivery and migration (tow item, tipping porosity (air dilution), tobacco menthol, and plasticizer) were incorporated into a full RSM experiment (31) to develop predictive capability for mentholated products (RDM 1984, No. 59 "The Effects of Cigarette Construction Parameters and Menthol Load on Menthol Cigarette Peformance", A. B. Norman, T. A. Perfetti, M. E. Poe, and J. B. Newsome, September 5, 1984). A four variable central composite design with five levels for each variable was chosen. The variable combinations are summarized in Table VIII. Correspondence between design unit values and actual target values for the variables is shown in Table IX.

Current SALEM LIGHT 85 blend was used for all samples but the menthol applied was varied according to the experimental design. Filter ventilation was obtained by on-line laser perforation. The various filter pressure drop levels required by the experimental design were obtained by choosing tow items which yielded the appropriate draft near mid-point capability. The tow items which correspond to the design levels for filter draft are shown in Table X. The plasticizer used was triacetin (E-18) with no menthol. Filter length was 27-mm, tobacco rod length was 57-mm and cigarette cirumference was 24.8-mm for all product. (Detailed specifications for the test products are given in Appendix A of the RDM which can be obtained from the R&D Library.) All cigarettes were aged for three weeks prior to any analyses.

o Results and Discussion

The averaged results of all cigarette smoke and physical analyses are included in the RDM (31). Several responses were calculated from the smoke analysis results: menthol and nicotine filtration efficiencies, menthol/'tar' ' and nicotine/'tar' ratios, and "menthol transfer efficiencies".

Although this study was designed to investigate menthol-related performance attributes, information was collected which allows construction of regression models (26) to predict non-menthol smoke deliveries and cigarette pressure drops. The effects of the variables on FTC 'tar', nicotine, TPM, CO, CO2, and vents open (DHO) and vents closed (DHC) pressure drops were as expected from the results of previous work (1,2,4,6,7). 'Tar', nicotine, TPM, and DHO were significantly (alpha $<$ 0.10) correlated with filter pressure drop and ventilation levels. No significant effects of plasticizer level or menthol load were observed for these responses. Variation in the gas phase responses, CO and CO2, was explained primarily by ventilation level. The regression models obtained for these responses were excellent as evidenced by the high multiple r-squared values. The predictive capabilities of the models were also tested and were found to be quite good as show in Figures 1-4 and Table XI.

Menthol analyses performed for this study were divided into two parts. For unsmoked cigarettes, pack menthol and menthol on the filters and tobacco rods were measured. After smoking, smoke menthol deliveries and menthol on the filters were measured. These quantities allowed computation of menthol filtration efficiencies, menthol/'tar' ratios, and menthol transfer efficiencies for the products.

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It was found that although no menthol was ap[illegible] cigarettes, significant amounts of menthol had migrated from the tobacco rods into the filters. The amount of menthol found on the filters was significantly correlated with the tobacco menthol load but not with the other variables.Similarly, measured tobacco rod and pack menthol levels were significantly correlated only with the amount of menthol applied to the tobacco. These results suggest that, at a given time, migration of menthol to the filter is determined mainly by the amount of menthol present.

Other workers (25,27,28) have shown that level and type of plasticizer may weakly influence the amount of menthol which migrates to the filter. Woods (27) recently reported that, at a given time after cigarette preparation, menthol found on the filters increased with plasticizer levels. Our model constructed for filter menthol gave a statistically significant regression coefficient for the effect of plasticizer level, even though the correlation was not significant. This indicates that the effect of plasticizer level on migration is minor. Interestingly, the amount of menthol found on the tobacco rod did not yield a significant regression coefficient for plasticizer level. If plasticizer level affects migration of menthol then one would expect that as levels of plasticizer increase, more menthol would be found on the filter and less menthol would be found on the tobacco rod. In addition, menthol on the tobacco rods and filters should sum to a constant value at a given tobacco menthol load, regardless of plasticizer level. In Figures 5a, 5b, and 5c, filter menthol, tobacco menthol, and their sum are plotted versus tobacco menthol load for each of three plasticizer levels. As evident from the graphs, filter menthol amounts increase with applied menthol levels but decrease with increasing plasticizer levels. The total menthol (i.e., filter + tobacco) exhibits the same behavior but to a lesser degree. This observation may suggest incomplete accounting for the total menthol distributed throughout the cigarette. If it is considered that plasticizer affects menthol migration and the efficiency of recovery of menthol from filters in the analytical method used, then a plausible explanation might be that as plasticizer levels increase, less menthol can be extracted for analysis. It is probable that this rationalization accounts for the discrepancy between Norman et al. (31) and Woods (27), since the analytical technique used in Woods' study did not rely upon extraction of menthol from the filters.

In the Norman et al. study, menthol deliveries were significantly correlated with filter draft, ventilation level, and tobacco menthol load. A small but statistically significant regression coefficient was also found for plasticizer level. The effect for plasticizer level would account for a change of about 0.04 mg menthol delivery over the range of plasticizer levels studied. Therefore, this effect is minor in comparison to the effects of the other variables. The effect of plasticizer level on menthol delivery at several ventilation and filter draft levels, as computed from the models, is shown in Figure 6. As expected, as filter draft and ventilation levels were increased, menthol deliveries decreased. Moreover, the menthol delivery at a given FTC 'tar' depends on the particular combination of filter draft and ventilation levels used. Figure 7 shows a plot of 'tar' versus menthol delivery as calculated from the regression models. To obtain each of the curves shown, filter draft was varied over the range studied and 'tar' and menthol deliveries were computed. As shown by the graphs, at a given 'tar' level slightly more menthol is delivered as ventilation levels are increased. This finding is supported by an analysis of menthol/'tar' ratios. Tobacco menthol load was detemined to be most important to menthol delivery per unit 'tar'. The relationship between menthol/'tar' ratio and ventilation for different filter draft levels is shown in Figure 8. Figure 8 shows that at lower filter draft levels, the menthol

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delivered per unit 'tar' increases with ventilation. Thus, filter draft must have an effect on menthol delivery which is similar to its effect on 'tar'. The effect of ventilation on 'tar' delivery is greater than its effect on menthol. The observations on the effects of filter draft and ventilation levels on menthol/'tar' are similar to those found for the variation of nicotine per unit 'tar'. This may indicate that the mechanisms of nicotine and menthol filtration and transport within the smoke stream are qualitatively similar.

Menthol filtration efficiencies were computed by two different methods. In the first method, the total amount of menthol found on the filters after smoking was divided by the sum of the smoke menthol deliveries and the menthol on the filters before smoking. Obviously, this method of computation includes any menthol which migrated to the filter in the overall filtration efficiency. Regression analysis indicated that filtration efficiency for menthol was mainly affected by filter draft and ventilation level. Plasticizer level and tobacco menthol load also gave significant, but relatively small, regression coefficients. This method of computation gave filtration efficiencies ranging from ~72 % to ~90 %. Because these values seemed excessively high, a second method of computation was used. In the second method, the menthol found on the filters prior to smoking was subtracted from the "post-smoking" values and the efficiencies re-calculated. Interestingly, even with the exclusion of migrated menthol, filtration efficiencies ranged from ~53 % to ~85 %. The menthol filtration efficiencies observed were about 20 units greater than those for nicotine and about 10 units larger than those for TPM. Regression analysis for the second method of computation gave results similar to the first, except that no significant effect of tobacco menthol load was found. Apparently, the effect of tobacco menthol noted for the first computation method was "cancelled" when migrated menthol was removed in the second computation method. The effect of plasticizer level on the efficiency of menthol filtration was much larger when the second method of computation was used. In this case, menthol filtration efficiency increased by ~12 units over the range of plasticizer levels studied. The increasing menthol filtration efficiency with increased plasticizer level qualitatively agrees with the results described earlier for the effect of plasticizer on menthol delivery. However, menthol deliveries did not change as much as expected based on the range of filtration efficiencies observed. This could be a consequence of the efficiency of menthol extraction from filters during the analysis procedure, as discussed above.

The fraction of menthol applied to the tobacco that is ultimately delivered in the smoke was also computed. This fraction is the menthol smoke delivery divided by the sum of the menthol found on the filters and tobacco rods prior to smoking. The values for this measure of "menthol transfer" ranged from ~ 4 % to ~ 12 %. Regression analysis of this response revealed significant first-order effects of filter draft and ventilation levels. Application of more menthol to the tobacco did not increase the transfer rate. The menthol transfer was found to decrease with increasing draft or ventilation.The effect of ventilation on menthol transfer at various filter drafts is shown in Figure 9. The absolute effects of filter draft and ventilation on menthol transfer rates can be altered to a degree, depending upon the combination of draft and ventilation levels used. Figure 10 shows a plot of menthol transfer as a function of FTC 'tar', where filter draft was varied to effect the changes in 'tar'. As apparent from Figure 10, menthol transfer generally increases with increasing 'tar' deliveries. However, at a given 'tar' level, menthol transfer can be very slightly increased by the combination of lowered filter drafts and increased ventilation. This observation is similar to that for smoke menthol deliveries discussed above.

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To further analyze aspects of the transfer of menthol to smoke, the fraction of menthol applied to the tobacco which enters the filter was calculated by adding the smoke menthol deliveries to the amount of menthol deposited on the filters after smoking (e.g., post-smoking minus pre-smoking). The result was then divided by the total menthol applied to the cigarettes (e.g., menthol applied X weight of tobacco per cigt.). These values ranged from ~ 20 % to ~ 34 %. Regression analysis indicated that this measure is influenced by each of the four variables studied. The significance of this measure is that the maximum amount of menthol that can be transferred to the smoke (per unit applied) is very small. Adjustment of the cigarette parameters evaluated in this study can do little to improve this transfer efficiency.

The overall results of this study provide specific information on the quantitative effects of tow item, tipping porosity (air dilution), tobacco menthol, and plasticizer on menthol related responses. The regression models indicate that small increases in menthol delivery may be obtained for a given 'tar' delivery and/or tobacco menthol load. Table XII was constructed to illustrate the range of menthol related responses that can be expected from variations in filter draft and ventilation levels when FTC 'tar' deliveries remain constant. In Table XII the menthol load (0.5%) and plasticizer level (8%) were held constant while filter draft and ventilation were varied over the ranges studied such that the computed FTC 'tar' delivery was constant at 8 mg/cig. The remainder of the data in Table XII were calculated from the regression models with the variable values indicated. For the first two estimates (150mm and 136mm filter drafts, respectively), menthol deliveries, filtration efficiencies, and transfer rates were similar. Moderate changes in cigarette draft, nicotine and CO deliveries, and TPM and nicotine filtration efficiences were estimated. A substantial change in smoke menthol delivery was not noted until the filter draft was lowered to 63 mm and the ventilation level raised to 52.5%. In this case, the menthol delivery was increased by only 15% relative to the estimate made for 0% ventilation. Although the effects of the changes in cigarette design on the menthol parameters were minor, major changes occurred in the other responses estimated for this product.

Table XIII was constructed to show how menthol delivery might be maximized for a given FTC 'tar' level and tobacco menthol load. As in Table XII, the tobacco menthol load was held constant at 0.5% while filter draft and ventilation levels were varied to maintain estimated FTC 'tar' at 9 mg/cig. The first two entries in Table XIII (110 mm and 63 mm filter drafts) are the constructions from Table XIII where menthol deliveries began to increase. The third entry (50mm filter draft) represents the minimum filter draft/maximum ventilation combination allowed by the constraints of the regression models. In this case, an increase in menthol delivery of 3.3% was observed. Further increases in menthol delivery by adjustment of plasticizer levels could not be obtained.

It appears from the above analyses that the range of control for menthol deliveries is extremely limited when the 'tar' delivery and the tobacco menthol load are arbitrarily fixed. From the practical point of view, the variables studied are only capable of causing "co-variations" in the deliveries of menthol and 'tar'. The data indicates clearly that the delivery of menthol is very inefficient on a per unit menthol applied basis. Moreover, the major cigarette design features (filtration efficiency and ventilation) cannot be used to effect substantial increases in menthol delivery efficiency. It is apparent that more novel approaches are required to improve the efficiency of menthol usage.

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o Conclusions of Menthol Parameter Study

The results of this study can be used to estimate the effects of filter draft, ventilation level, applied tobacco menthol, and plasticizer level on delivery and migration of menthol. The estimates made from the models can be used to assist in the design of mentholated cigarettes for production and research studies. This study did not provide information to assist in improving the efficiency of menthol delivery. It appears that for the cigarette configurations studied, efficiency of transfer and delivery of menthol is very low. There are indications that menthol delivery can be increased (per unit menthol applied) at a given 'tar' delivery level by adjusting the filter efficiency, ventilation level, and plasticizer level. Although the models can be used to maximize the menthol delivery for a particular level of applied menthol, the resulting cigarette design may not perform well from the consumer response point of view and indeed may be very different from current configurations. Moreover, the maximized menthol deliveries were only slightly greater than values estimated for more typical cigarette designs.

Some additional work was suggested based on the results of this study. The results indicate that the method of analysis for menthol on filters may be influenced by the level of plasticizer. Therefore, it was recommended that improved filter menthol analysis procedures be investigated. Also, additional investigations could be performed to determine the role of elution of menthol from filters as functions of various plasticizer types and levels. This information could lead to improved fundamental understanding of mentholated cigarette performance. Finally, some efforts need to be directed toward identification of more efficient methods of delivering menthol. The results of this study show that, at best, only about 34 % of the menthol applied to the tobacco reaches the smoke stream. Typically, only ~10 % of the applied menthol is delivered from the cigarette. Some method of menthol incorporation into the filter which hinders migration to the tobacco rod could substantially increase the efficiency of menthol delivery and could thus lower the amounts of menthol applied to cigarettes. Investigation of a means to improve usage of menthol has great potential econommic benefits.

These regression models are currently being used by Applied R&D to assist them in the design of mentholated cigarettes.

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TABLE VIII.[1] EXPERIMENTAL DESIGN FOR THE MENTHOL PARAMETER STUDY

4 Variable Central Composite RSM Design
Full Replicate - Uniform Precision

PRODUCT	FILTER DRAFT	TIP DILUTION	% TUB MENTHOL	% FILTER PLASTICIZER
1	1.000	1.000	1.000	1.000
2	1.000	1.000	1.000	-1.000
3	1.000	1.000	-1.000	1.000
4	1.000	1.000	-1.000	-1.000
5	1.000	-1.000	1.000	1.000
6	1.000	-1.000	1.000	-1.000
7	1.000	-1.000	-1.000	1.000
8	1.000	-1.000	-1.000	-1.000
9	-1.000	1.000	1.000	1.000
10	-1.000	1.000	1.000	-1.000
11	-1.000	1.000	-1.000	1.000
12	-1.000	1.000	-1.000	-1.000
13	-1.000	-1.000	1.000	1.000
14	-1.000	-1.000	1.000	-1.000
15	-1.000	-1.000	-1.000	1.000
16	-1.000	-1.000	-1.000	-1.000
17	-2.000	0.000	0.000	0.000
18	2.000	0.000	0.000	0.000
19	0.000	-2.000	0.000	0.000
20	0.000	2.000	0.000	0.000
21	0.000	0.000	-2.000	0.000
22	0.000	0.000	2.000	0.000
23	0.000	0.000	0.000	-2.000
24	0.000	0.000	0.000	2.000
25	0.000	0.000	0.000	0.000
26	0.000	0.000	0.000	0.000
27	0.000	0.000	0.000	0.000
28	0.000	0.000	0.000	0.000
29	0.000	0.000	0.000	0.000
30	0.000	0.000	0.000	0.000
31	0.000	0.000	0.000	0.000

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TABLE IX. DESIGN UNITS VERSUS ACTUAL TARGET VALUES FOR VARIABLES OF RSM DESIGN

VARIABLE	LABEL
1	FILTER SEGMENT DRAFT
2	FILTER DILUTION
3	% TUB MENTHOL
4	% PLASTICIZER ON FILTERS

VARIABLE	TRANSFORMATION		
1	DESIGN = (ACTUAL -	111.258072) /	30.000000
2	DESIGN = (ACTUAL -	34.809669) /	17.500000
3	DESIGN = (ACTUAL -	0.554190) /	0.200000
4	DESIGN = (ACTUAL -	8.458389) /	3.000000

VARIABLE	DESIGN MINIMUM	DESIGN MAXIMUM	ACTUAL MINIMUM	ACTUAL MAXIMUM
1	-1.875269	2.124731	55.000000	175.000000
2	-1.983410	1.913733	0.099998	68.300003
3	-1.970950	2.029050	0.160000	0.960000
4	-1.846130	1.627204	2.919999	13.340002

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TABLE X. TOW ITEMS CORRESPONDING TO DESIGN LEVELS FOR FILTER DRAFT OF RSM DESIGN

Tow Item	Mean Filter Segment Draft (S.D.)	Design Unts
5.0/35000	56.4 (0.17)	-2
3.9/42000	81.6 (1.45)	-1
2.7/46000	114.9 (1.14)	0
1.8/46000	139.4 (1.72)	+1
2.1/48000 w/TJ*	176.1 (0.70)	+2

TJ = Transport Jet

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Table XI. Cigarette Sample Series used for Regression Model Tests.

Data used for Computations[a]				Observed Analysis Results				
Filter Draft (mm H2O)	Ventilation (%)	Plasticizer (%)	Pack menthol[b] (%)	FTC 'Tar' (mg/cig)	Nicotine (mg/cig)	CO (mg/cig)	Smoke Menthol (mg/cig)	DHO[c] (mm H2O)
105	24	9.1	0.59	8.9	0.72	11.0	0.32	131
109	28	9.1	0.66	8.8	0.70	10.5	0.29	134
102	19	9.6	0.59	9.3	0.74	11.1	0.39	127
99	21	9.1	0.61	10.4	0.77	12.3	0.49	122
102	22	8.9	0.60	10.4	0.74	12.6	0.58	129
109	18	9.0	0.71	9.0	0.71	10.3	0.38	132
87	20	9.0	0.60	10.3	0.80	12.4	0.56	124
78	51	9.0	0.46	7.8	0.59	8.2	0.30	80
103	41	9.0	0.52	7.6	0.61	7.9	0.38	115
107d	37	9.0	0.14	8.3	0.71	10.7	0.07	117
107d	36	9.0	0.24	8.8	0.74	11.1	0.13	119
107d	35	9.0	0.34	8.9	0.75	11.2	0.18	124
107d	35	9.0	0.44	8.5	0.72	10.9	0.24	124
107d	38	9.0	0.53	8.4	0.72	10.8	0.36	117
107d	37	9.0	0.65	8.8	0.74	11.2	0.39	117
107d	36	9.0	0.79	8.8	0.72	10.3	0.50	121
107d	35	9.0	0.79	8.8	0.76	10.9	0.55	119
107d	36	9.0	0.89	8.8	0.73	10.9	0.63	118
124d	52	6.1	0.19	6.1	0.51	8.1	0.07	113
125d	51	6.1	0.30	6.4	0.54	8.4	0.13	112
125d	53	6.1	0.40	6.1	0.53	7.7	0.19	111
123d	53	6.1	0.50	6.0	0.50	7.5	0.24	109
122d	53	6.1	0.62	5.9	0.53	7.2	0.31	111
123d	53	6.1	0.74	6.0	0.53	7.5	0.37	111
121d	53	6.1	0.81	6.0	0.54	7.2	0.42	109
122d	54	6.1	0.93	5.7	0.51	6.9	0.42	109
124d	51	6.1	1.21	5.9	0.52	7.2	0.55	111

a. Filter lengths were 25 or 27 mm, tobacco rod lengths were 59 or 57 mm as noted below. Cigarette circumferences were 24.8 mm. Vent and filter constructions varied, as well as tobacco blend. Data shown are results from standard cigarette analyses obtained after making.

b. Tobacco menthol load (i.e., "tub menthol") data were not available in all cases. Pack menthol values are slightly lower than tub menthol (see regression analysis, Appendix B).

c. Cigarette pressure drop with vents open.

d. Filter length was 25 mm, tobacco rod length was 59 mm. Filter draft was adjusted to an "equivalent draft for 27 mm" by multiplication of the listed value by the factor (25/27) before use with the models. No compensation for tobacco rod length difference was used.

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TABLE XII. THE INFLUENCE OF CIGARETTE DESIGN ON SMOKE DELIVERIES AT THE SAME FTC 'TAR' LEVEL AS ESTIMATED FROM THE REGRESSION MODELS

Filter Draft	(mm)	150	136	110	63
Ventilation	(%)	0	17.5	35	52.5
Tobacco Menthol	(%)	0.5	0.5	0.5	0.5
Plasticizer	(%)	8	8	8	8
FTC 'Tar'	(mg/cig)	8.0	8.0	8.0	8.0
Nicotine	(mg/cig)	0.58	0.63	0.67	0.74
Menthol	(mg/cig)	0.26	0.26	0.27	0.30
CO	(mg/cig)	13.1	11.5	9.4	6.3
Puff Count		6.8	7.0	7.3	7.9
DHO 1	(mm)	197	161	118	66
Menthol/'tar'	(ug/mg)	33.6	32.3	33.3	38.6
Menthol Transfer 2	(%)	7.2	8.0	8.5	9.7
Menthol Filtration Efficiency 3	(%)	76.6	75.3	71.8	61.4
TPM Filtration Efficiency	(%)	69.3	67.5	62.2	47.2
Nicotine Filtration Efficiency	(%)	60.2	58.3	53.5	39.0

[1] Cigarette pressure drop with vents open.

[2] 100 X (Smoke menthol delivery/Total menthol applied)

[3] 100 X (filter menthol)/(filter menthol + menthol delivry)
where:
filter menthol = (Post smoking - Pre smoking filter menthol)

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TABLE XIII. COMPONENT CHANGES TO MAXIMIZE MENTHOL DELIVERY FOR 8 mg FTC 'TAR' LEVEL WITH 0.5% APPLIED TOBACCO MENTHOL

Filter Draft	(mm)	110	63	50	50
Ventilation	(%)	35	52.5	56	57
Tobacco Menthol	(%)	0.5	0.5	0.5	0.5
Plasticizer	(%)	8	8	8	4
FTC 'Tar'	(mg/cig.)	8.0	8.0	8.1	8.0
Nicotine	(mg/cig.)	0.67	0.74	0.76	0.78
Menthol	(mg/cig.)	0.27	0.30	0.31	0.31
CO	(mg/cig.)	9.4	6.3	5.5	5.8
Puff Count		7.3	7.9	8.0	8.1
DHO 1	(mm)	118	66	54	56
Menthol/'tar'	(ug/mg)	33.3	38.6	40.5	39.9
Menthol Transfer 2	(%)	8.5	9.7	10.1	9.7
Menthol Filtration 3 Efficiency	(%)	71.8	61.4	57.6	52.8
TPM Filtration Efficiency	(%)	62.2	47.2	41.9	42.5
Nicotine Filtration Efficiency	(%)	53.5	39.0	33.7	32.3

[1] Cigarette pressure drop with vents open.

[2] 100 X (Smoke menthol delivery/Total menthol applied)

[3] 100 X (filter menthol)/(filter menthol + menthol delivery)
where:
filter menthol = (Post smoking - Pre smoking filter menthol)

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Figure 1. Comparison of Computed and Observed FTC "Tar" Deliveries for Test Products.

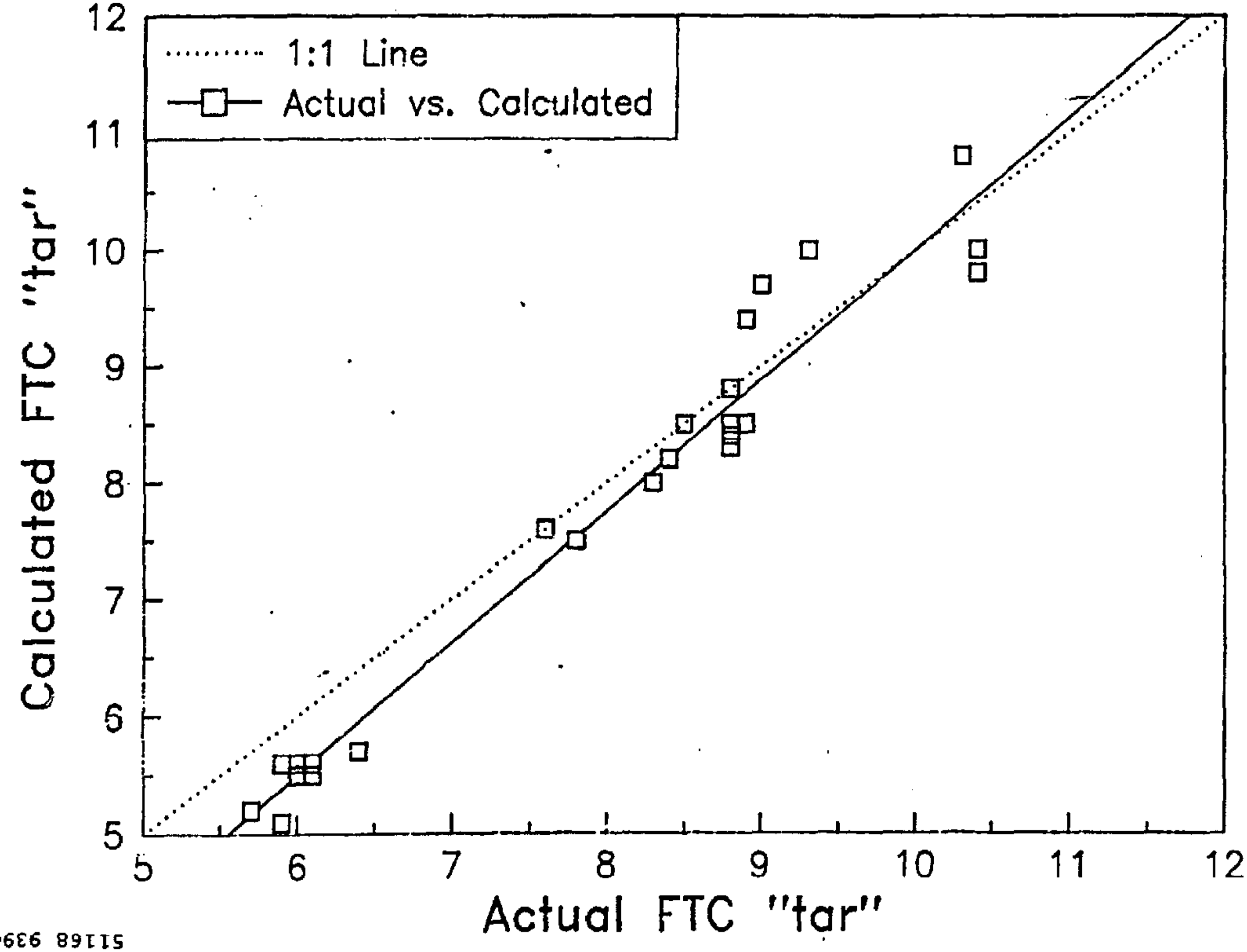

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Figure 2. Comparison of Computed and Observed
Nicotine Deliveries for Test Products

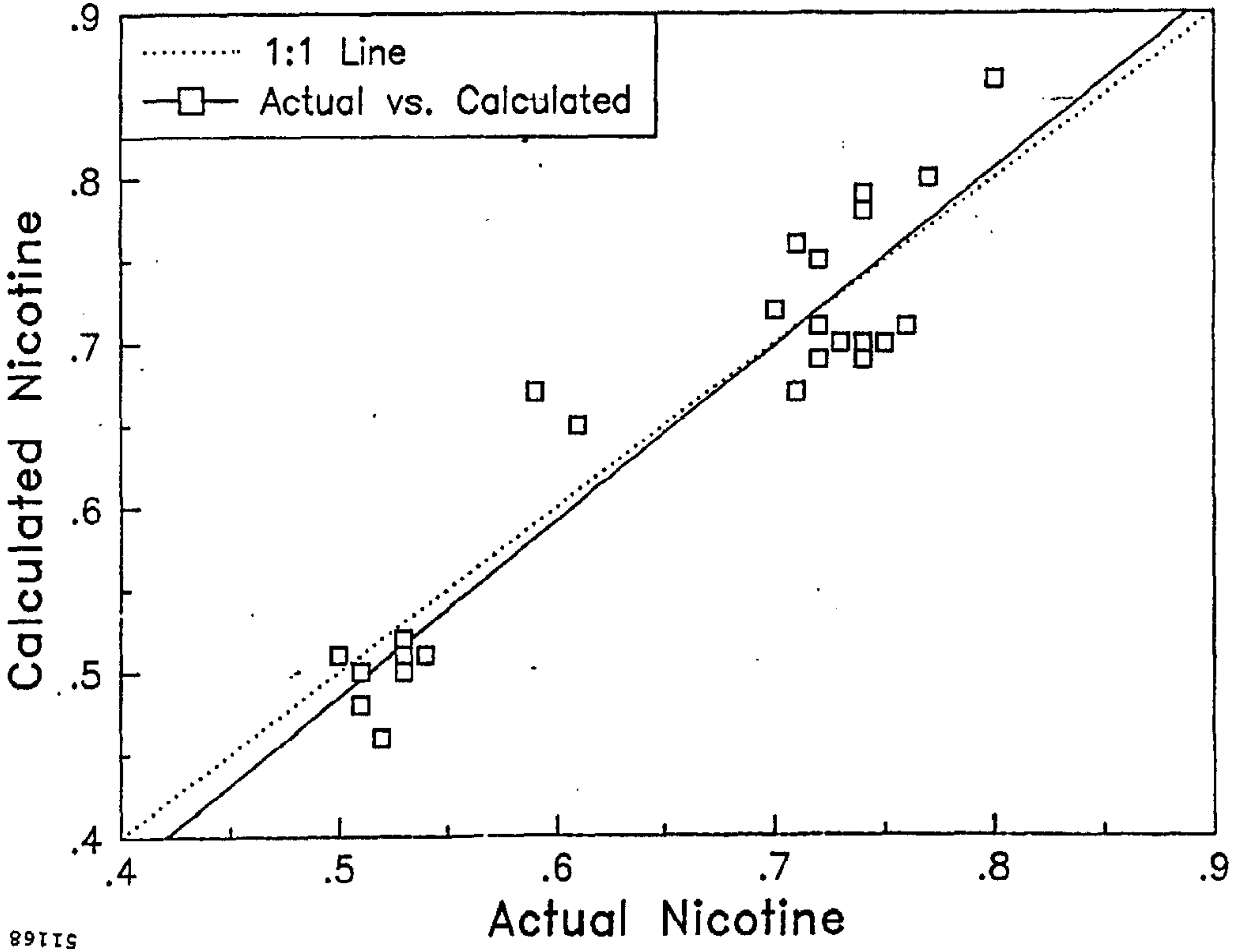

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Figure 3. Comparison of Computed and Observed Menthol Deliveries for Test Products

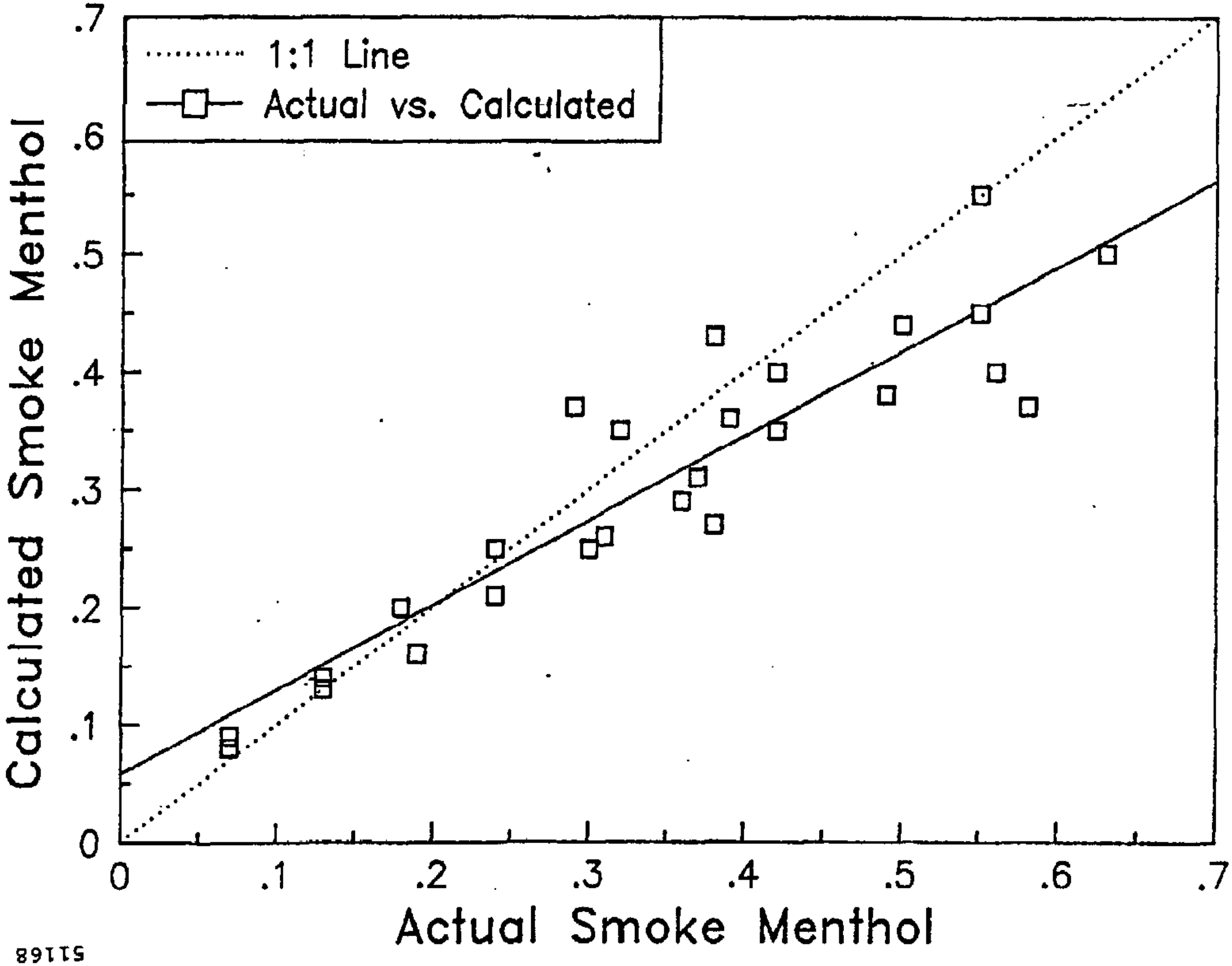

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Figure 4. Comparison of Computed and Observed Cigarette Pressure Drops for Test Products

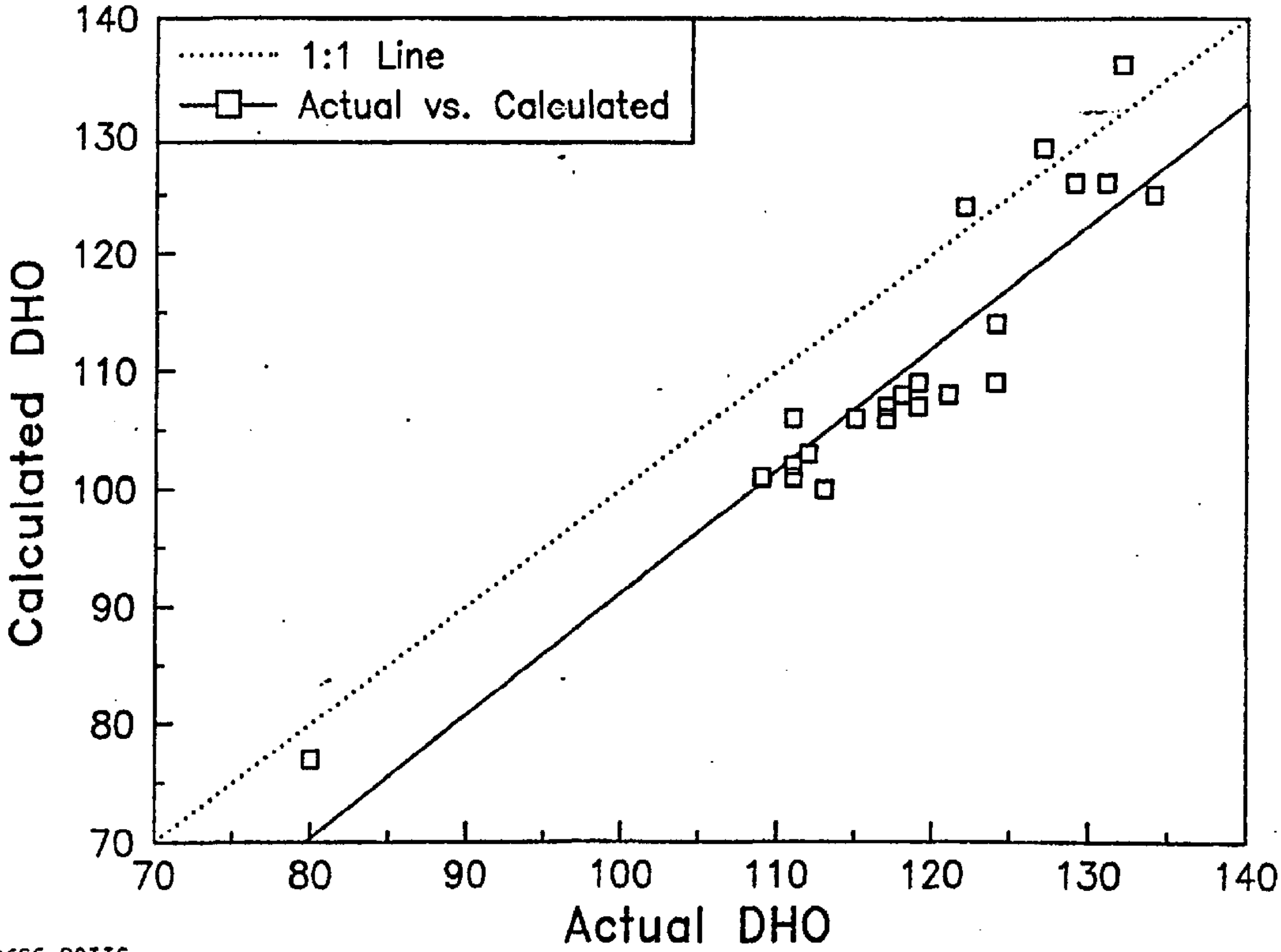

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Figure 5a. Computed Filter Menthol versus Tobacco Menthol Level for Various Plasticizer Levels

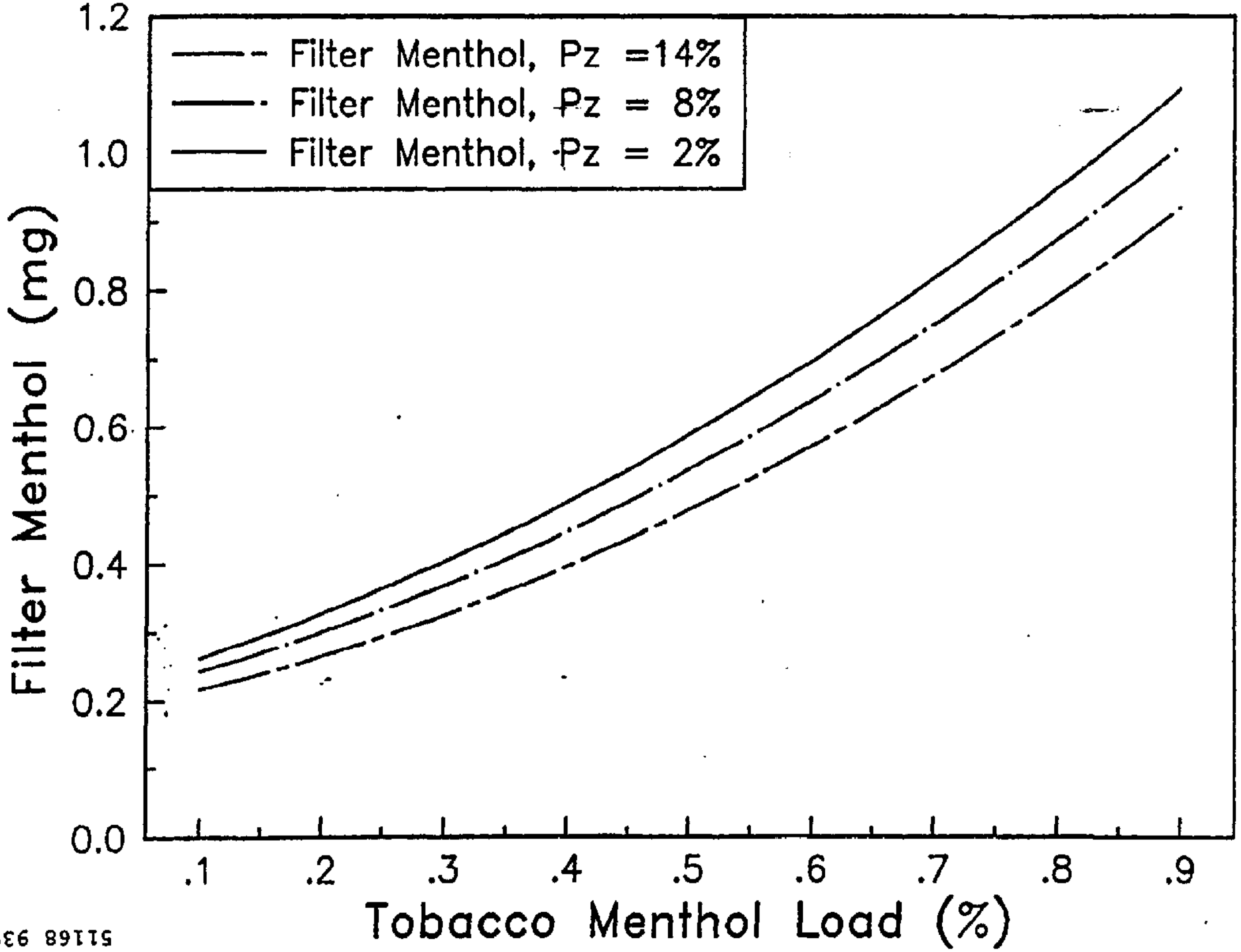

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Figure 5b. Computed Rod Menthol versus Tobacco Menthol Level for Various Plasticizer Levels

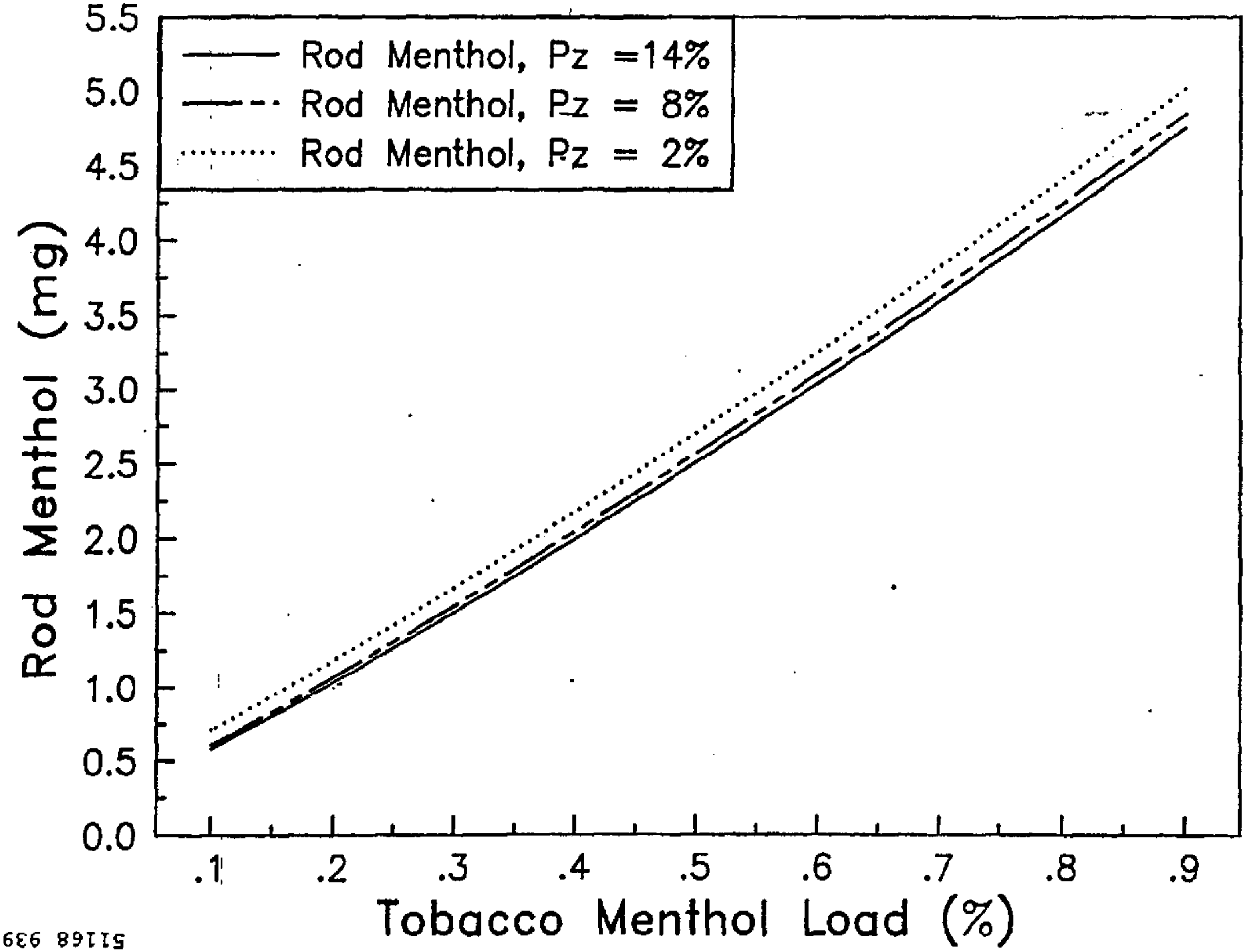

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Figure 5c. Computed Total Menthol versus Tobacco Menthol Level for Various Plasticizer Levels

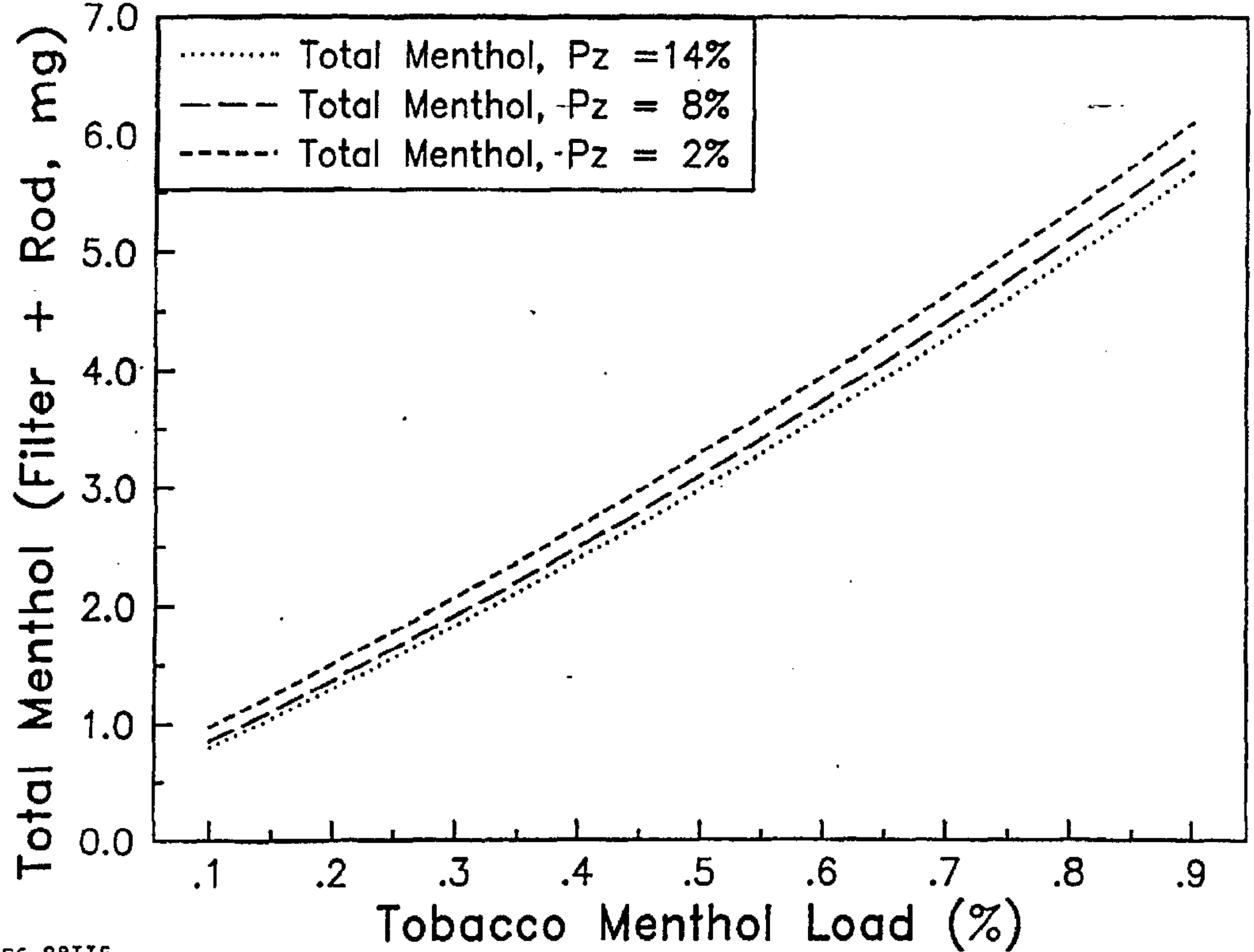

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Figure 6. Computed Menthol Delivery as a Function of Plasticizer Level

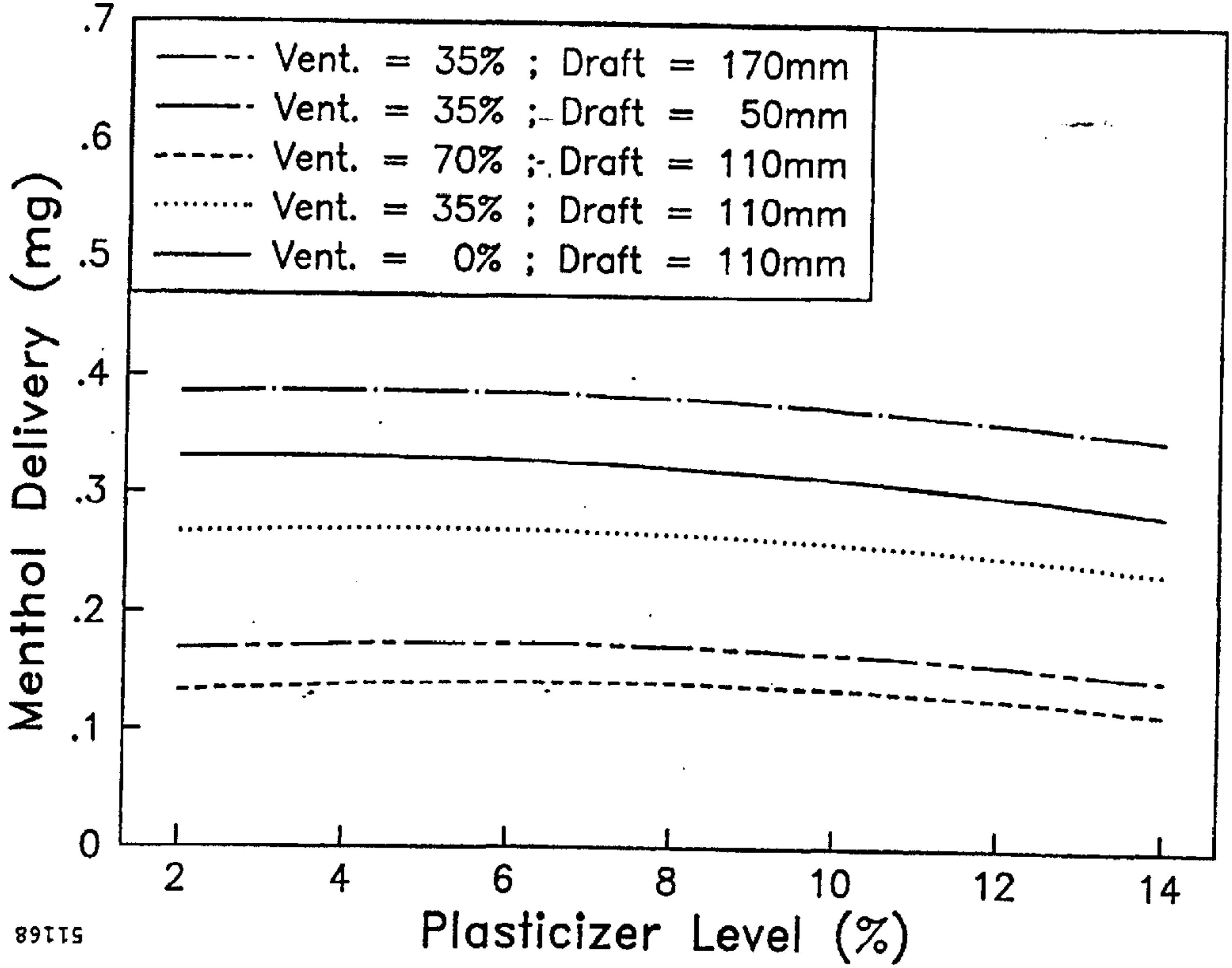

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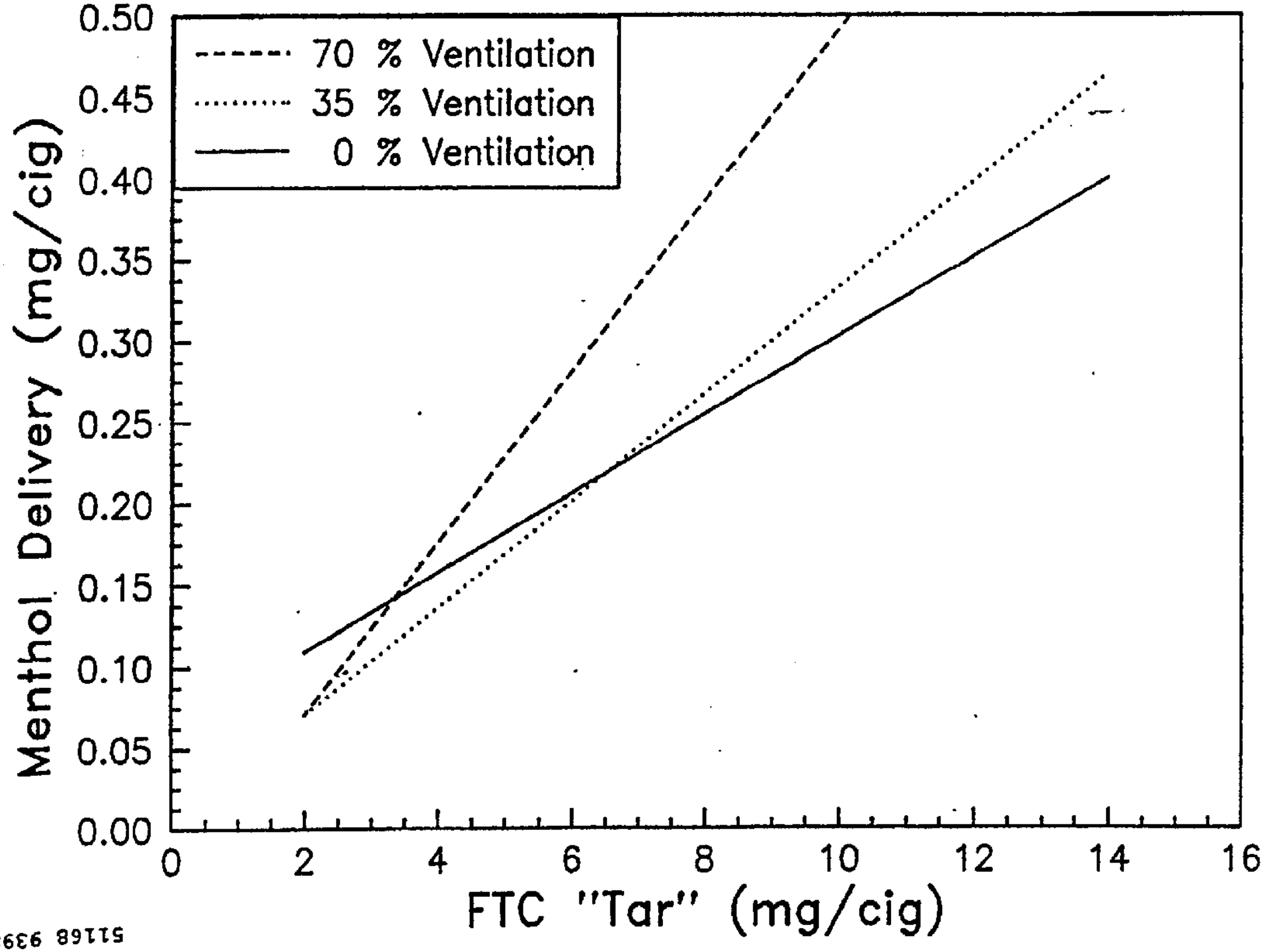
Figure 7. Computed Menthol Delivery as a Function of FTC "Tar"



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Fi...re 8. Computed Menthol/"Tar" ..atios versus Ventilation Level for Various Filter Drafts

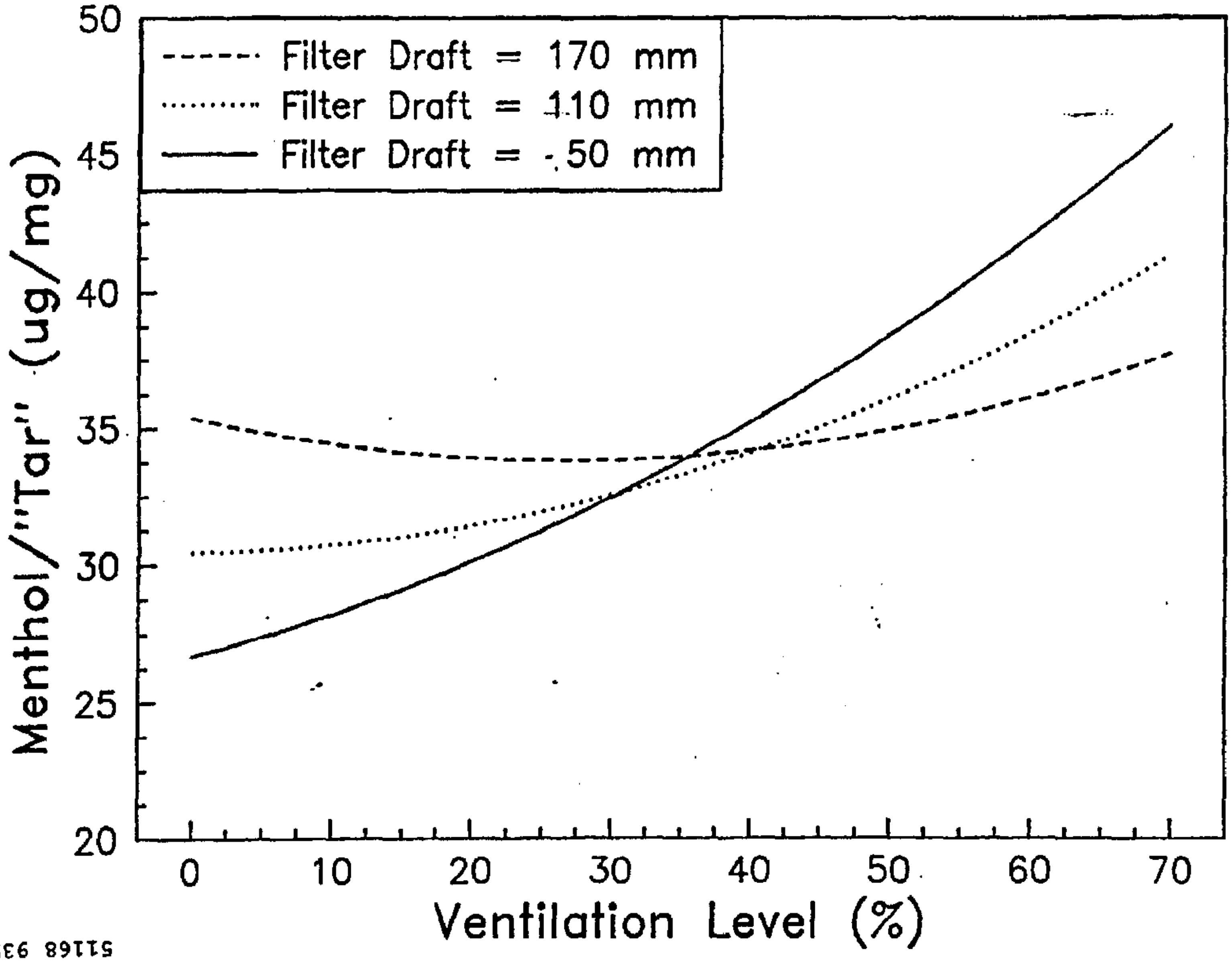

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Figure 9. Effects of Ventilation and Filter Draft on Fraction of Applied Menthol Delivered

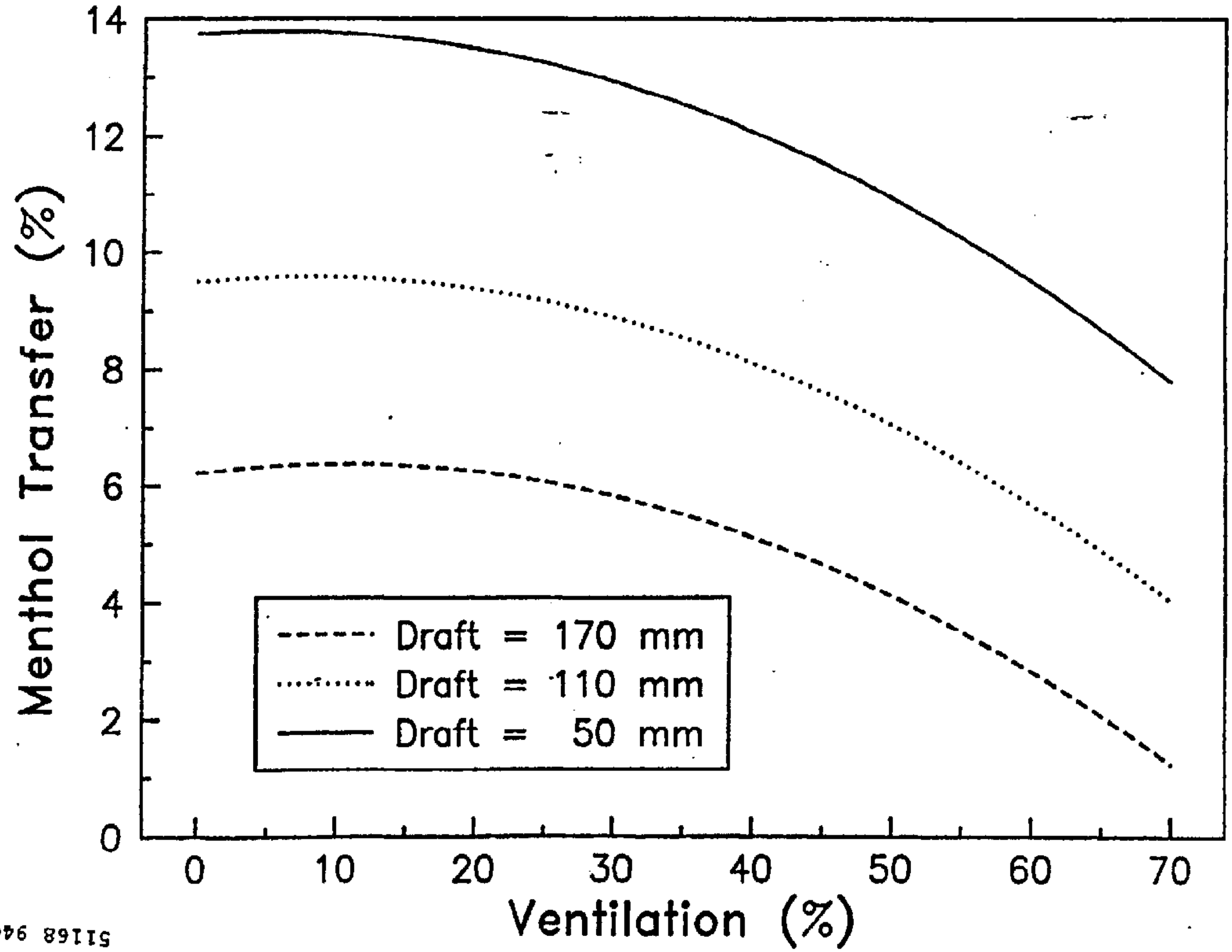

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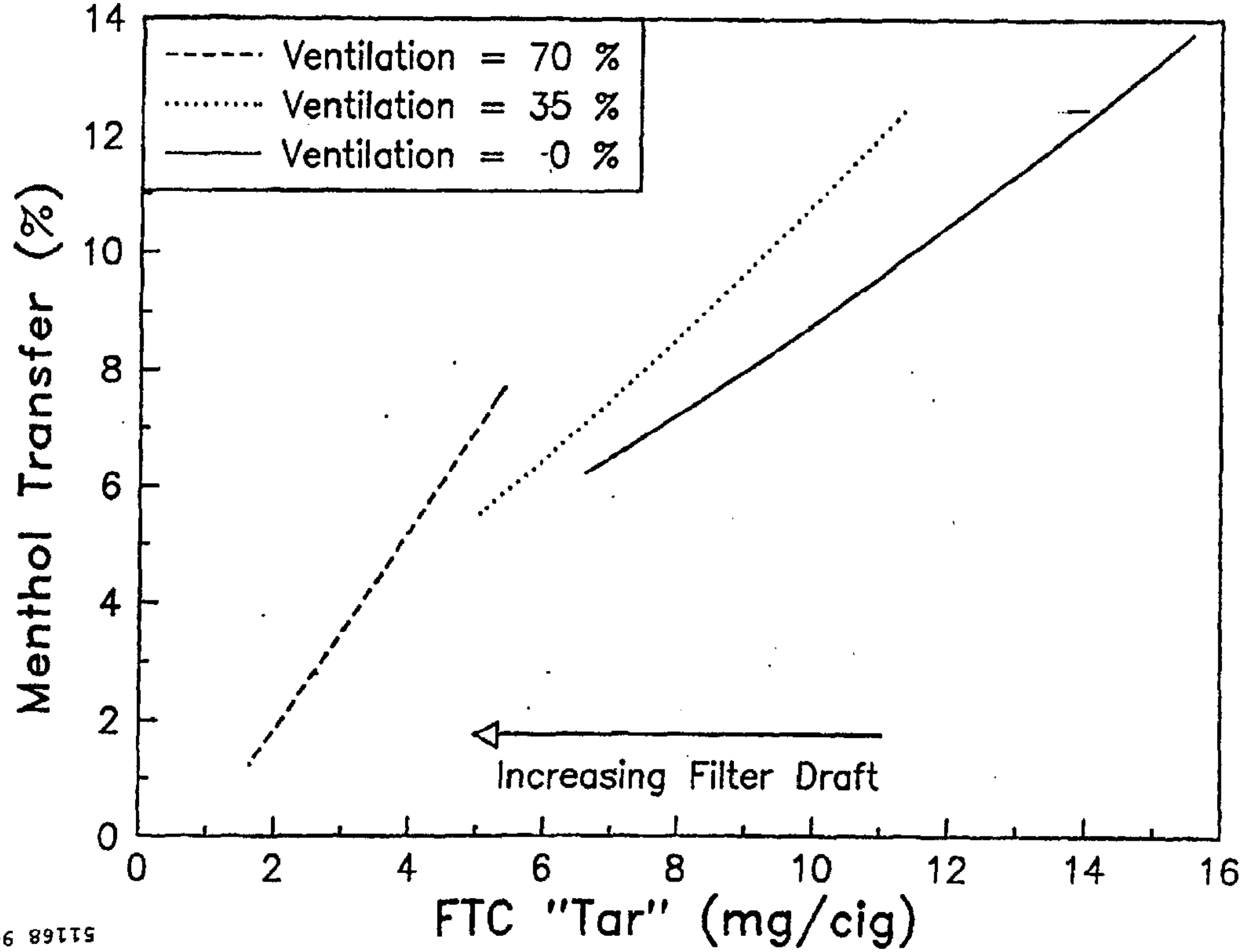
Figure 10. Menthol Transfer as a Function of FTC "Tar" Delivery as varied by Ventilation and Filter Draft



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